

Novel SOC and SOH Estimation Through Sensor Technology

Southwest Research Institute®

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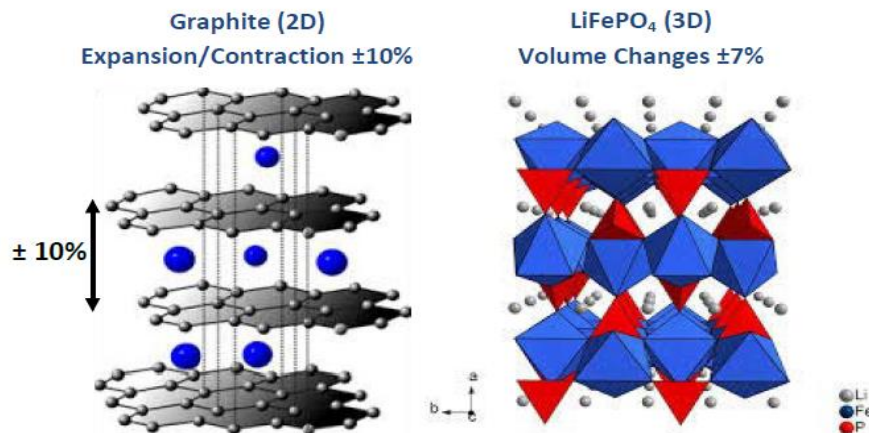
SwRI AMPED's Project Team:

- Jeff Xu, PI, principal scientist
- Joe Steiber, PI, principal engineer
- Craig Wall, project engineer
- Mickey Argo, project engineer
- Jayant Sarlashkar, staff engineer
- Cathy Schuler, coordinator
- Cheuk Ng, manager

Strain-Based Li-ion Batteries SOC/SOH Measurement System

Technology Description

- Strain correlates well with SOC/SOH and provides independent measure of them
- Volume changes measured externally to the cell instantaneously and in a robust fashion



Value Proposition

- No need to modify the cell – sensor is external to the cell
- Instantaneous current, SOC, and SOH measurement (direct and on-line)
- Allows failure prediction
- In combination with other algorithms, improves life and safety

Practical Aspects

- Accurate and low-cost
- Easy to implement – external to cell
- Excellent repeatability

<u>Metrics</u>	<u>State-of-Art</u>	<u>SwRI</u>
SOC accuracy	~5% error	~2.5% error
SOH sensitivity	N/A	0.00771%/cycle
SOH accuracy	N/A	~1.7% error

The Differentiation over the-State-of-the-Art

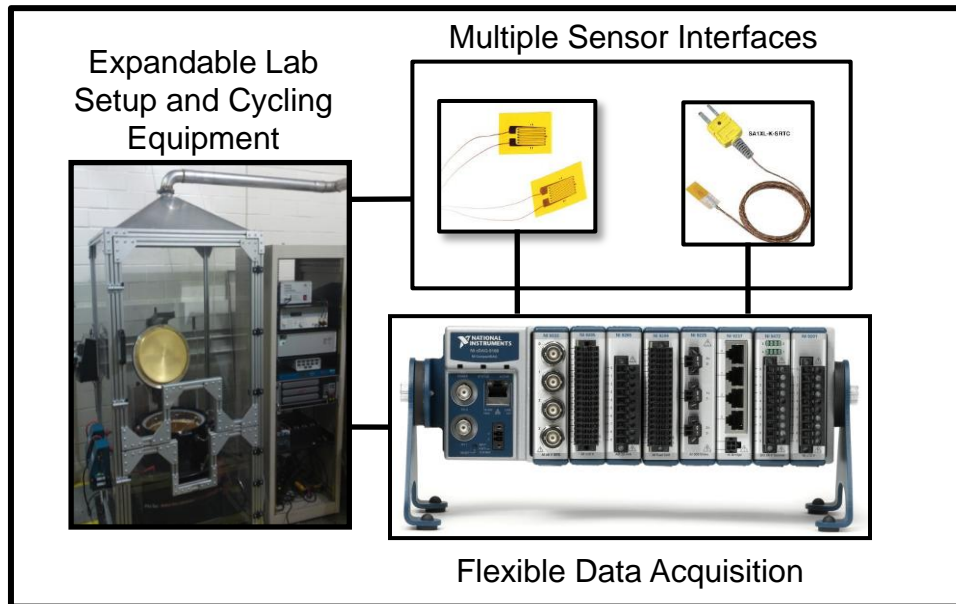
- Unlike present SOC/SOH estimations that rely primarily on indirect determination (OCV, coulomb counting, EKF, and model-based techniques)
- Combine fast and direct sensing hardware with modern control algorithms approach
- SOC determination based on a direct physical measurement
- No excessively complicated estimation algorithms
- No excessive parameterization of models
- Enhance the controllability and potential reliability of a battery pack

Key Questions from Battery Pack Manufacturers and System Integrators were Addressed and Demonstrated in the Project

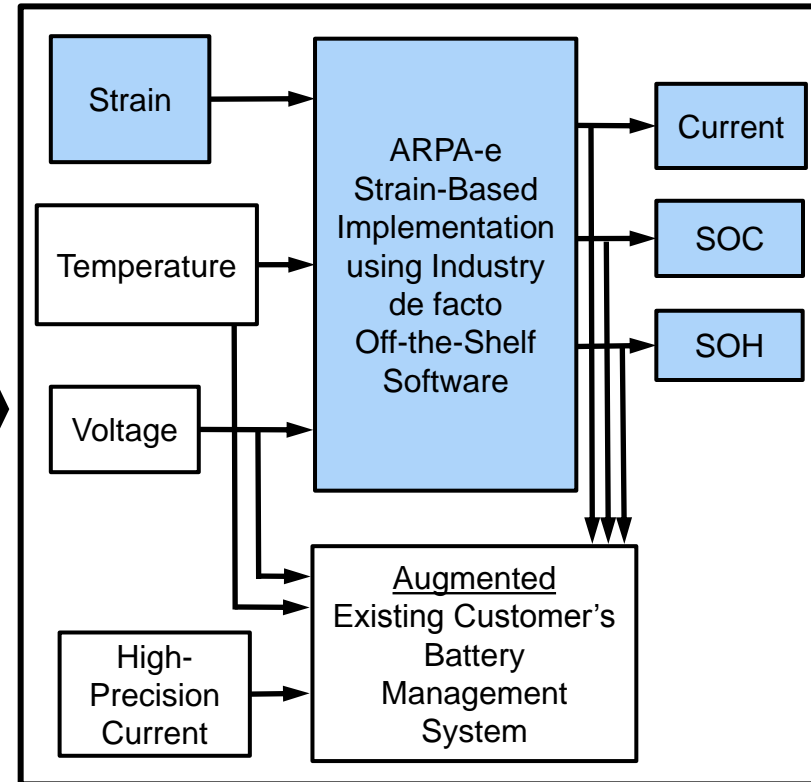
- Can the sensor accurately “measure” SOC at all?
- Can the sensor provide redundancy or elimination of current sensor (i.e., can it estimate current itself)?
- Can the sensor detect SOC under steady-state constant-current demands over the entire range of SOC?
- Can the sensor monitor SOH instantaneously as well as over the entire life of the cell?
- Can the sensor monitor SOC/SOH under increasingly demanding power demands?
- Can the sensor operate under highly-transient, realistic driving conditions?
- How consistent and accurate is the sensor signal over long-term transient conditions?

An Unconventional SOC/SOH Approach utilizing Strain-Based Hardware and Analysis

Battery Module Fixture & Data Acquisition

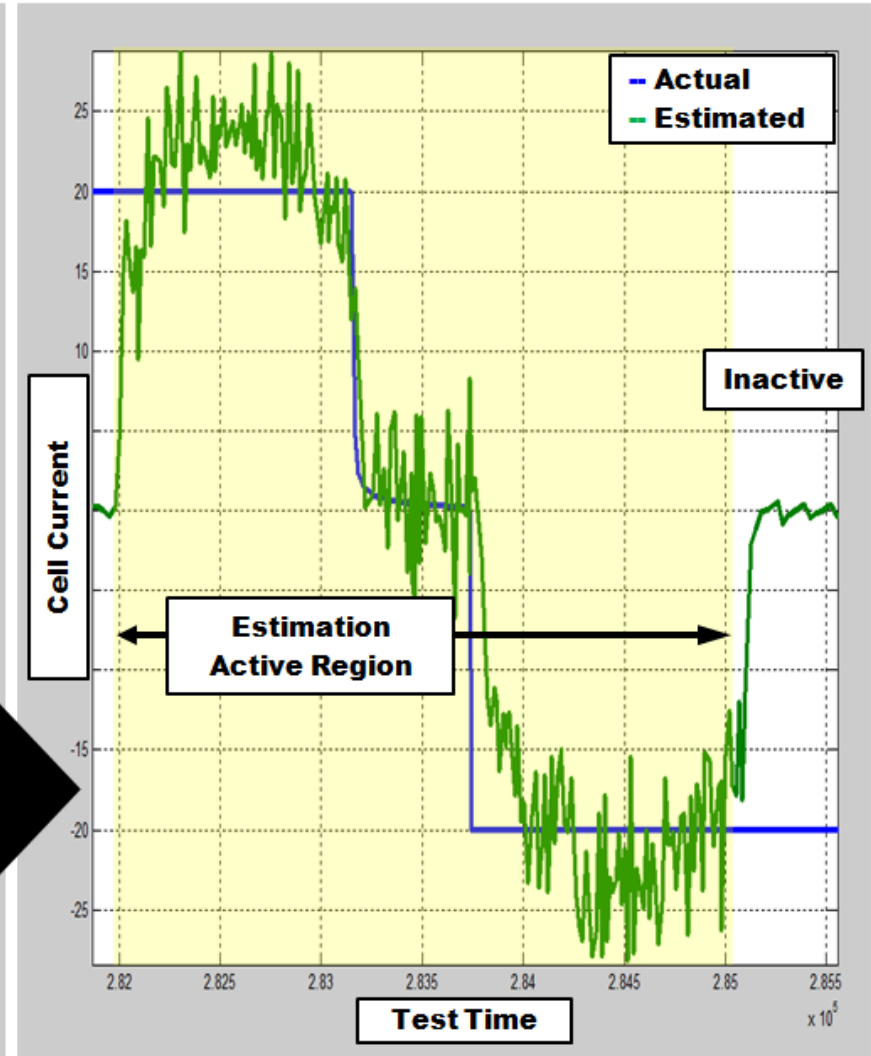
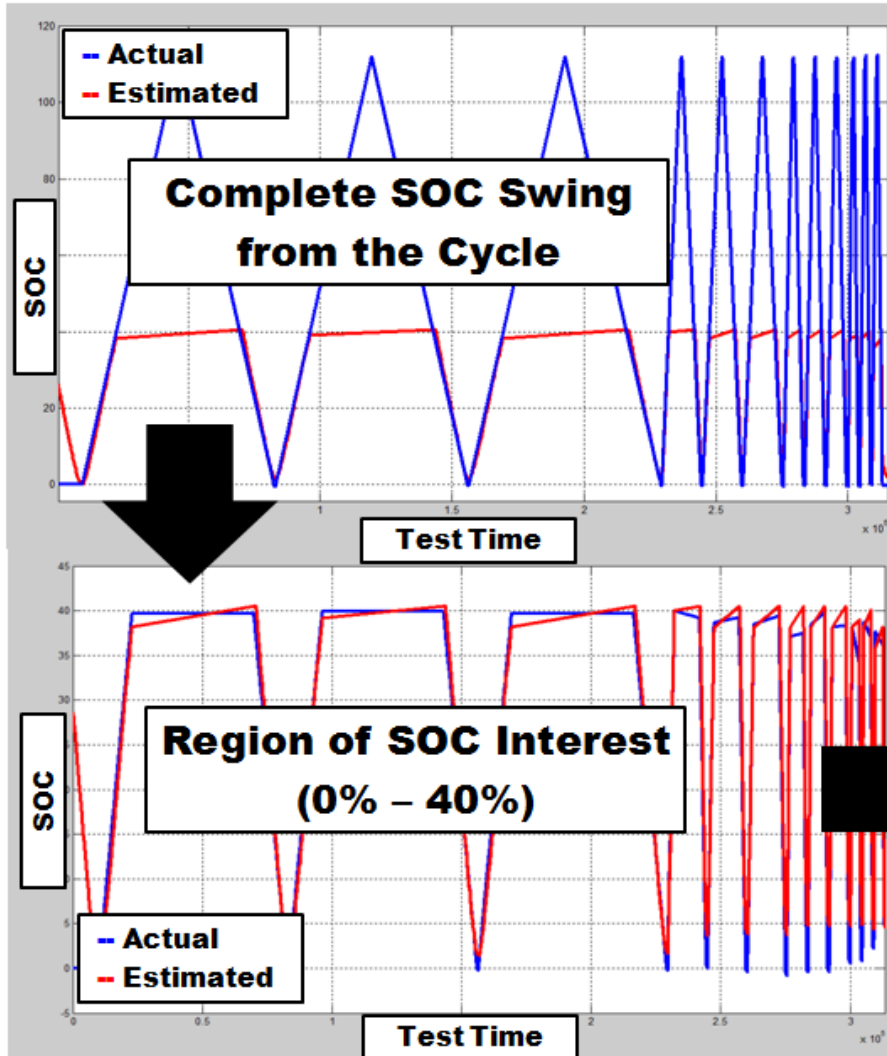


Control & Simulation Platform



Accuracy is better than the state-of-the-art over the entire life:
Error is <2% in the low SOC region (0-40%)
Error is ~1.7% for SOH

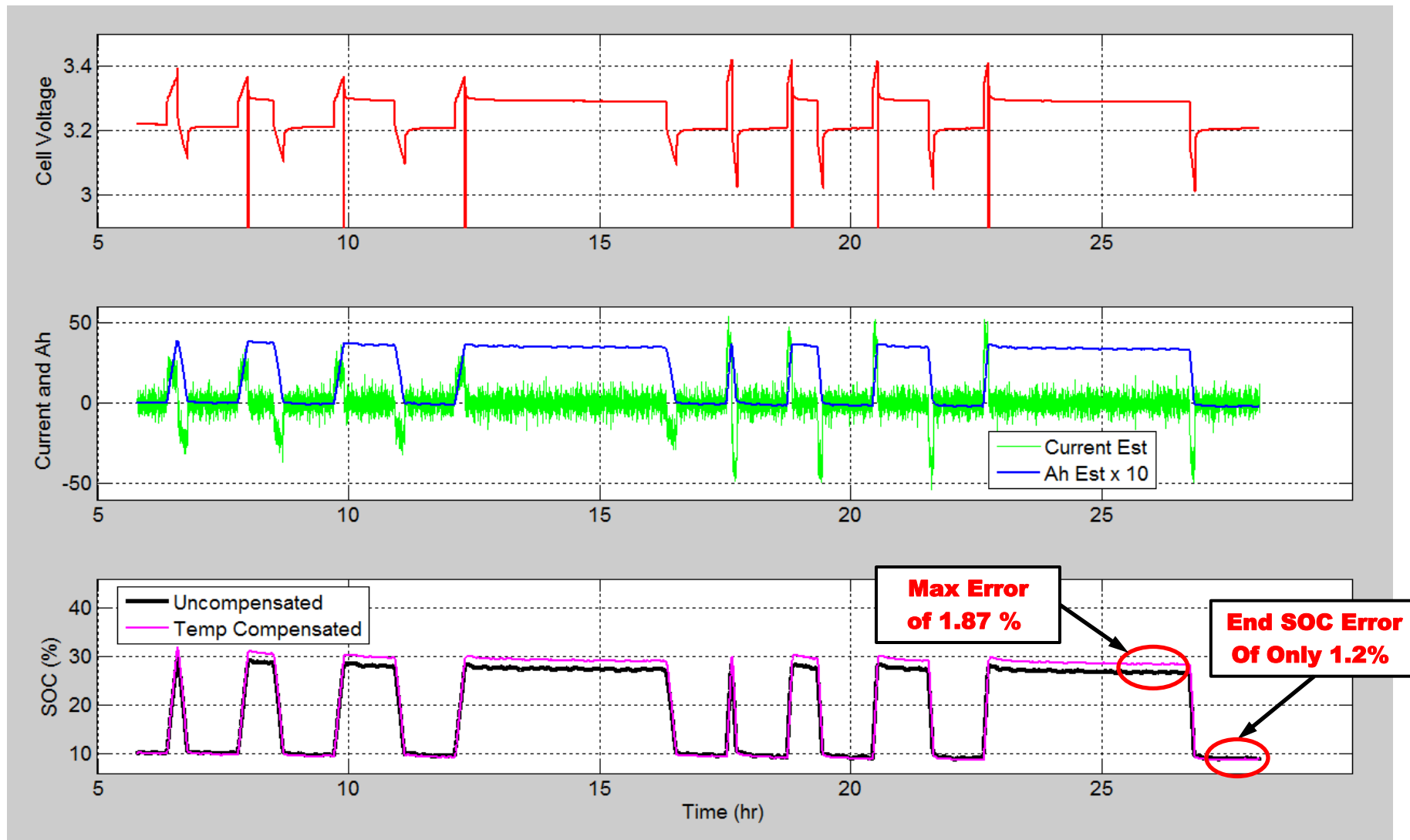
Demonstrated Instantaneous Tracking of SOC and Current on Increasingly Demanding Cycles



(20 Ah Prismatic LiFePO₄ Cell)

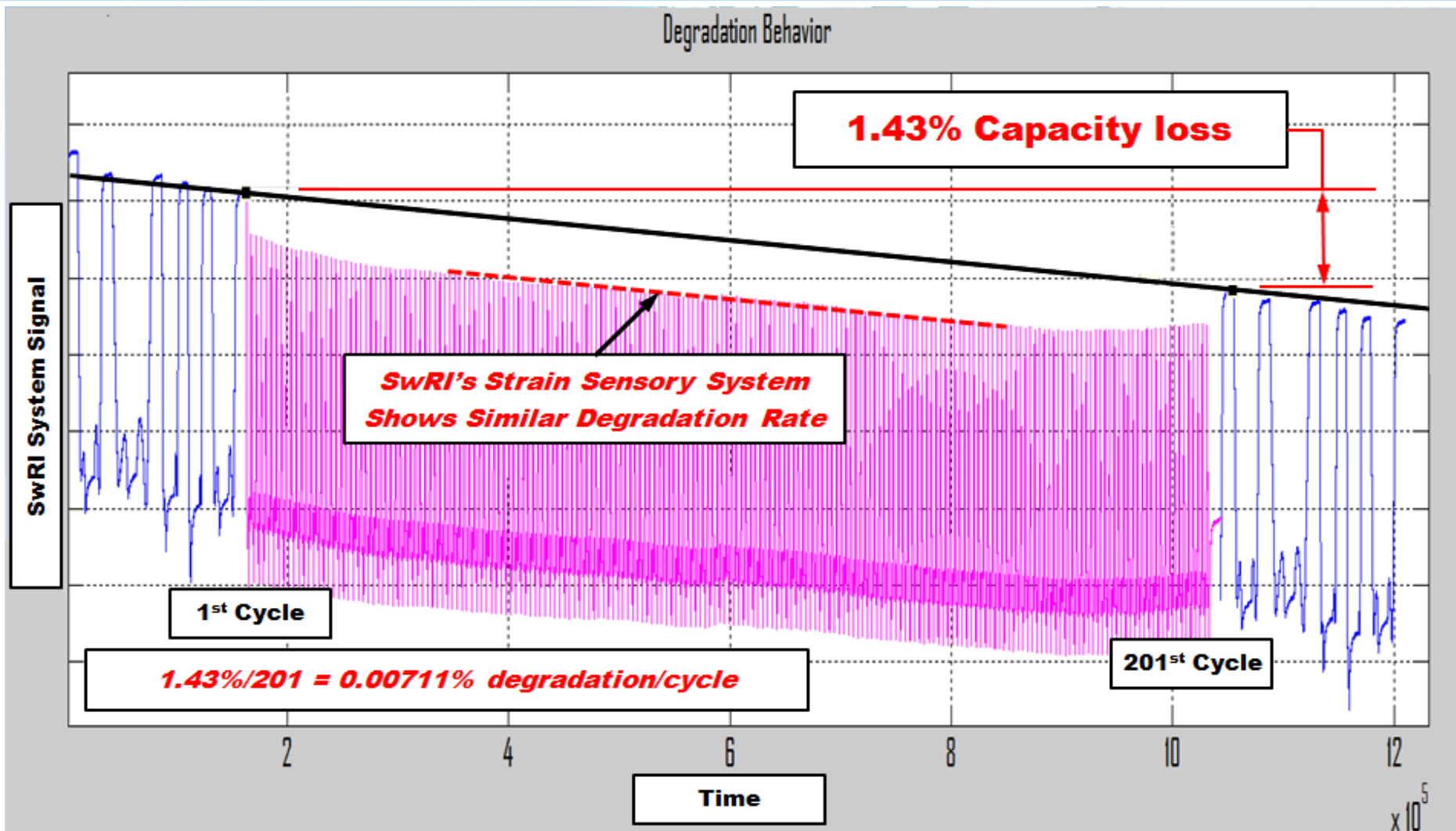
Validation of Sensor and Controller Software Technology

(Assessment of Potential Drift over an Extended Period of Time)



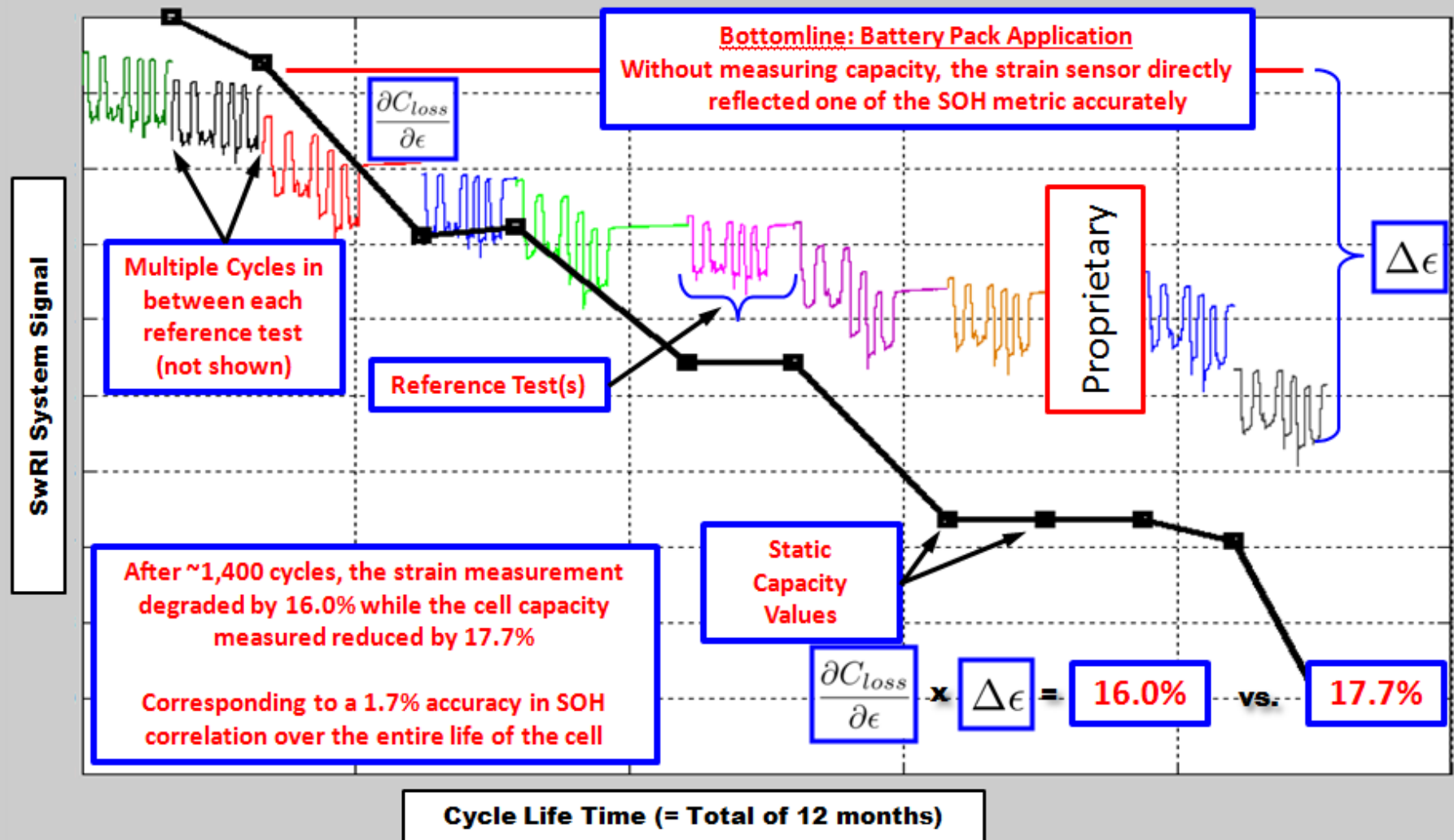
(20 Ah Prismatic LiFePO₄ Cell)

Validation of Instantaneous State-of-Health Determination (Short-Time Scale Sensing)

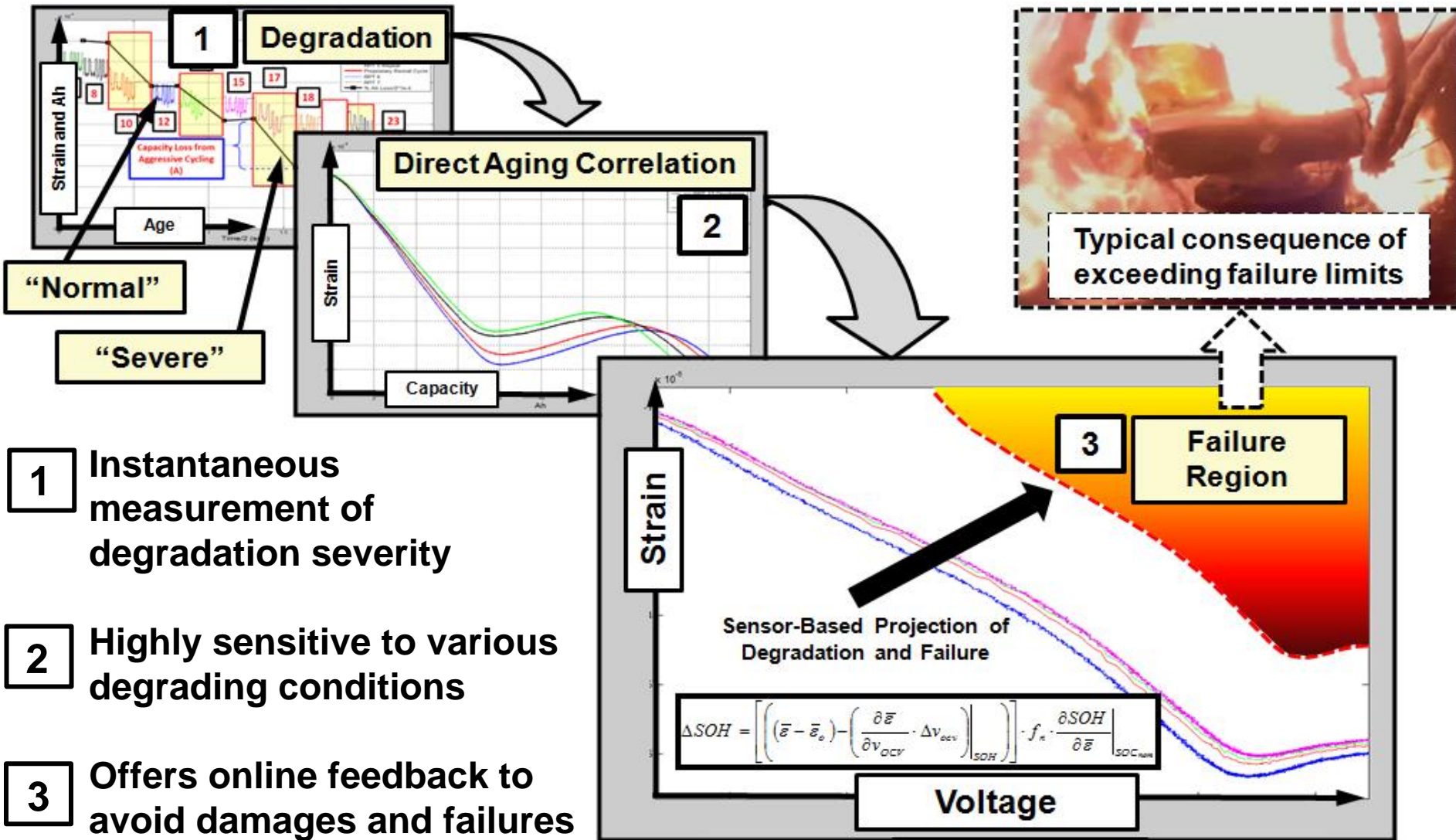


Shows that the degradation rate measured by the sensor matches the actual degradation of the cell during the cycling

Validation of Overall Degradation over the Entire Life Cycling of the Cell (Long-Time Scale Sensing)

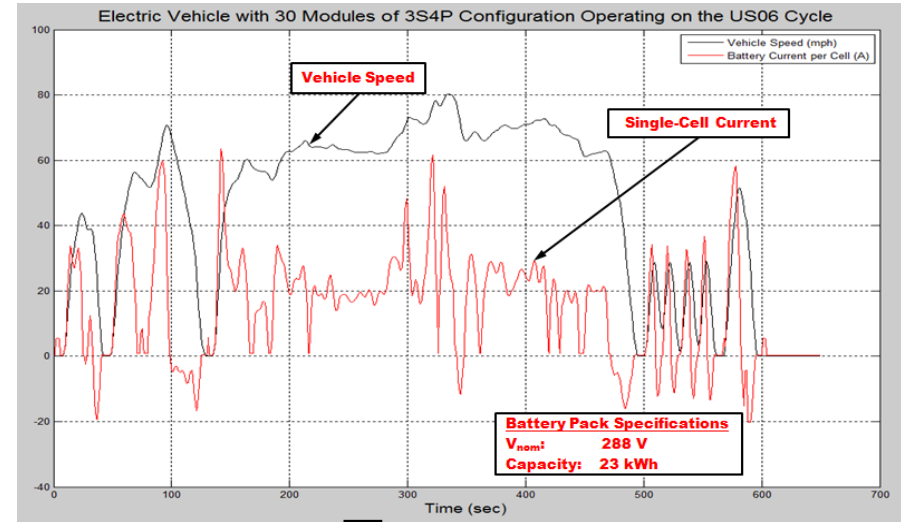


Strain Sensor Can Differentiate **Normal** from **Severe** Conditions due to Sensitivity to Degrading Factors which Allows Direct Correlation to Aging and Failures

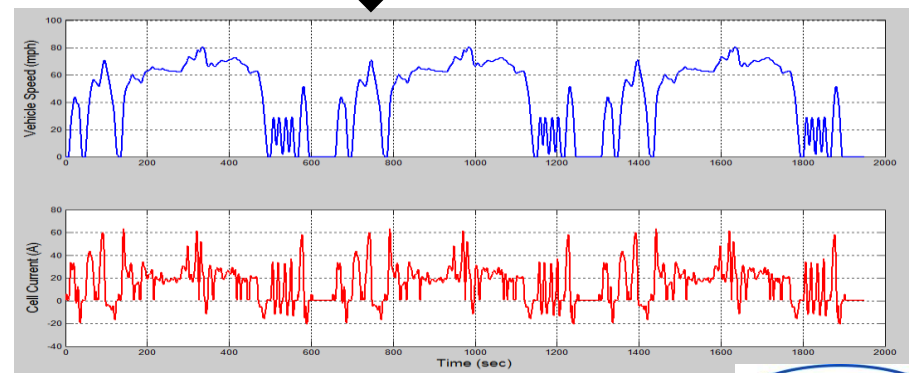


Major Validation Phase – Definition of Cell-Level Loading under the US06 Cycle for a Battery Pack Design

- A battery pack was designed for the purpose of this ARPA-e investigation
- It consists of 30 modules in series
- Each module contains 4 parallel strings of 3 cells in series
- Given the pack design, a vehicle comparable to the Nissan Leaf weighing around 1,450 kg was configured and simulated
- From the EV vehicle simulation, the dynamic loading on the cell for the US06 cycle was determined (8-mile trip)

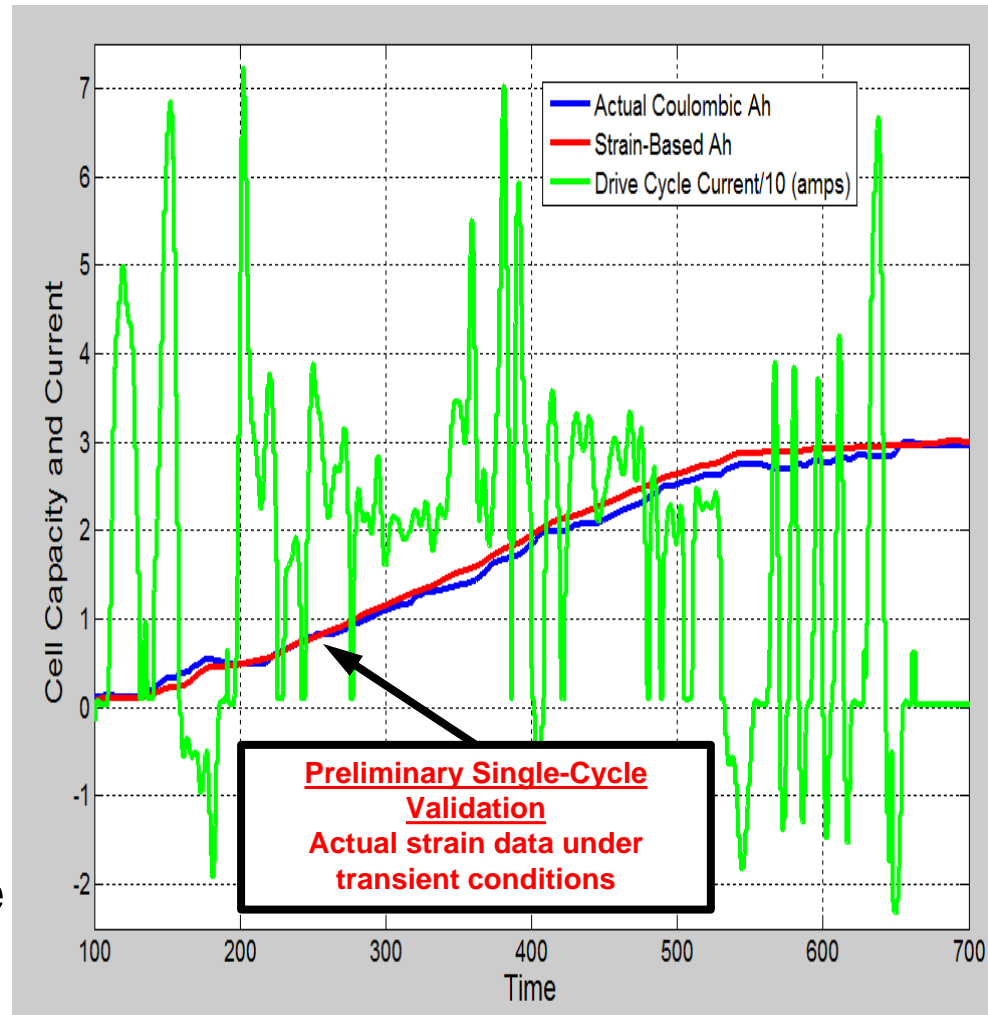


Creation of Multiple Consecutive Driving Cycles for Demonstration Purposes

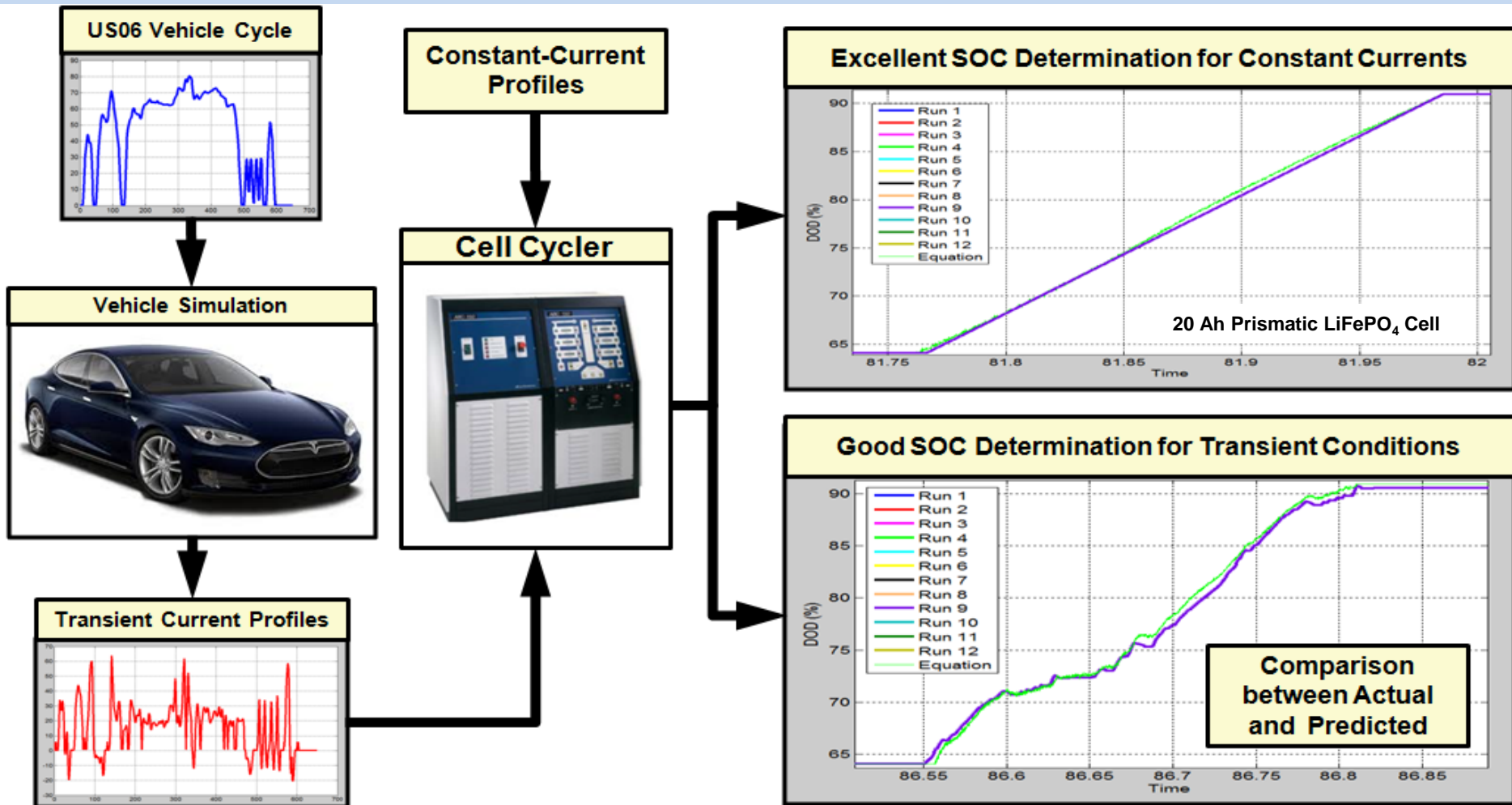


Validation Plan and Testing

- Validate Functionality over One Cycle
 - Cycle = 8 miles
- Validate over Entire SOC Range of Operation
 - Single Run = Five consecutive cycles = 40 miles
- Validate Characteristics over Extended Period (SOH)
 - Degradation Cycle = 12 consecutive 40-mile RUNS = 480 miles
- The cell is forced to provide the full power/energy required by the cycle over the entire range of SOC



Multiple Full-Transient Cycle Validations were Run Successfully with SOC Prediction Errors Less than 2.5% under Various Conditions



Strain-based SOC estimation approach quantitatively replicated/improved upon the state-of-the-art method of coulomb counting for both constant-current and transient-current operations

Project Results Address the Following Challenges

- Estimate SOC within 2.5% error on highly transient US06 driving cycles to Address Cell Manufacturers Challenges: Low Overhead SOC Determination Methods within Real World Context of Aging Cells
- Monitor SOH over the Entire Life of the Cell (1.7% difference from actual degradation) to Address Vehicle OEMs and System Integrators Challenges: Battery Remaining Useful Life Estimation and Cell Prognostic Information (Cycle/Life Expectancy)
- Estimate Instantaneous Degradation Rate (0.00711% change in capacity per cycle) to Address Vehicle OEMs Challenge: Prognostic Approach for Battery Failure
- Offer a Current-Sensorless Solution to Augment Estimation or Increase Redundancy of Existing Systems

Next Step – Partnership & Objectives

- Identify a Partner interested in the technology
- Take technology readiness level (TRL) from 4 to 6
- Make it robust, cheap, and lightweight for the application
- Customize the technology to augment existing BMS in order:
 - to achieve better accuracy and/or sensitivity
 - to detect finer cell behavior (e.g., new degradation signatures)
- Utilize the technology to identify damaging operating conditions in a given application (safer)
- Improve cell durability in a defined application



Thank You & Contact Us

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